Sporadic Model Building for Efficiency Enhancement of Hierarchical BOA

Martin Pelikan[1], Kumara Sastry[2], and David E. Goldberg[2]

[1]Missouri Estimation of Distribution Algorithms Laboratory (MEDAL)
University of Missouri, St. Louis, MO
http://medal.cs.umsl.edu/
pelikan@cs.umsl.edu

[2]Illinois Genetic Algorithms Laboratory (IlliGAL)
University of Illinois at Urbana-Champaign, Urbana, IL
{ksastry,deg}@uiuc.edu

Motivation

Background

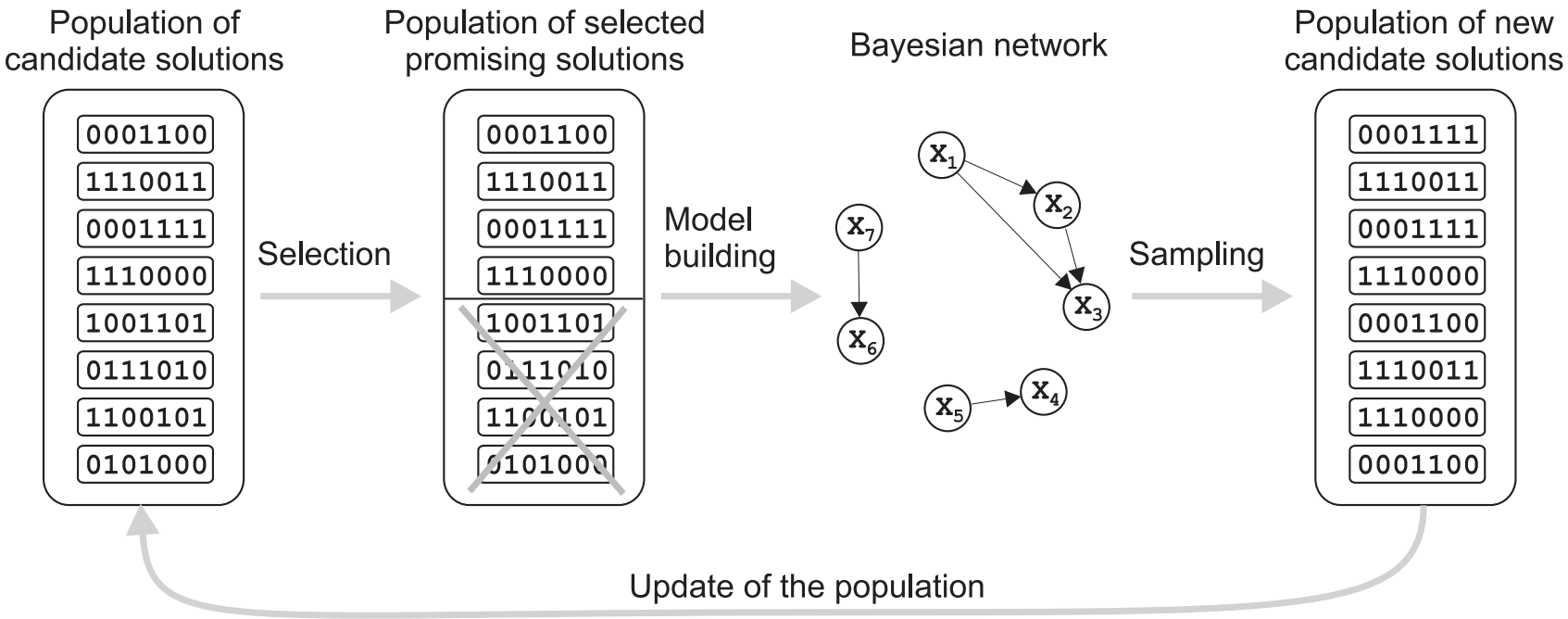
- Estimation of distribution algorithms (EDAs)
  - Scalable solution for many problems, often $O(n^2)$.
  - Often outperform standard optimization algorithms, making intractable problems tractable.
- Efficiency enhancement (EE)
  - $O(n^2)$ is sometimes not enough, we need further EE.
  - Reasons: Large n, expensive evaluation, online optimization.
  - Parallelization, fitness evaluation relaxation, hybridization, ...

Purpose

- Address model building in hierarchical BOA (hBOA).
- Use sporadic model building to speed up model building.
- Model-building speedup shown to increase with problem size.

Outline

Hierarchical BOA (hBOA)



Difference from standard genetic algorithms

Instead of applying crossover and mutation, hBOA builds and samples a probabilistic model (Bayesian network).

What to Speed Up in EDAs?

Computational bottlenecks in hBOA and other EDAs

- Potential bottlenecks
  - Fitness evaluation.
  - Model building.
- Fitness evaluation
  - Finite element analysis, simulations, interactive evaluation.
- Model building
  - High dimensionality, large subproblems in problem decomposition, many interactions, complex representations.

Efficiency enhancement

- Address the bottlenecks to further improve efficiency.
- Our focus: Speed up model building.

Efficiency Enhancement (EE) in EDAs

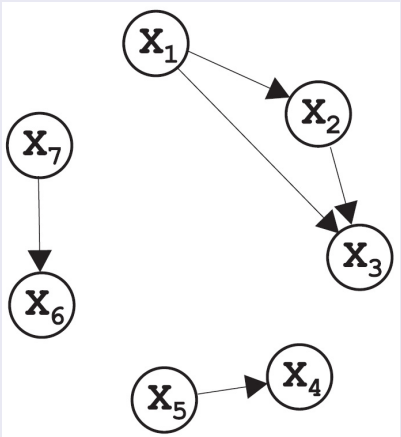
Classification of EEs for EDAs

1. Parallelization.
2. Hybridization.
3. Time continuation.
4. Fitness evaluation relaxation.
5. Prior knowledge utilization.
6. Incremental and sporadic model building.
7. Learning from experience.

Bayesian Networks

Bayesian network has two parts

- Structure
  - Structure determines edges in the network.



- Parameters.
  - Parameters specify conditional probabilities of each variable given its parents (variables that this variable depends on).
  - Example: $p(X_3|X_1, X_2)$.

Sporadic Model Building (SMB)

Complexity of model building in hBOA

- Two components of model building
  - Learn structure: complexity $O(kn^2N)$.
    N=population size
    k=order of subproblems
    n=number of bits.
  - Learn parameters: complexity $O(knN)$.

Sporadic model building: Basic idea

- Learn structure only in some generations.
- Remaining generations use structure from the previous iteration.
- Parameters are always updated.
- Goal: Save time in the most expensive part of model building.

SMB Schedule: When to Rebuild the Structure?

Question

How often to rebuild the network structure?

Simple schedule for SMB

- Use constant structure-building period t_{sb}.
- Learn structure in the first iteration.
- Then, learn structure in each t_{sb}th iteration.
- Examples
  - $t_{sb} = 1$: Learn in every generation.
  - $t_{sb} = 3$: Learn in every 3rd generation.

Tradeoff

- Learn too frequently $\rightarrow$ Small speedup.
- Learn too rarely $\rightarrow$ Models too bad to do well.

Effects of Sporadic Model Building

Effects of sporadic model building

- Speedup of structure building.
  - Due to building the structure only now and then.
  - Upper bounded by t_{sb}.
  - But a bit lower because of population sizing and convergence effects.
- Slowdown of evaluation.
  - Due to building imperfect models.
  - May lead to higher population sizes.
  - May lead to more generations.

Description of Experiments

Test problems

- Concatenated deceptive function of order 3.
- Concatenated trap function of order 5.
- Hierarchical trap.
- 2D spin glass (Ising, $\pm J$ couplings, periodic boundary cond.).

Two types of experiments

1. Vary t_{sb} to analyze its effects on hBOA performance.
2. Set t_{sb} automatically
   - Try a very small problem to find reasonable value of t_{sb}.
   - Ensure that $t_{sb} \propto \sqrt{n}$.
   - Done only for spin glass.

Description of Experiments (cont'd)

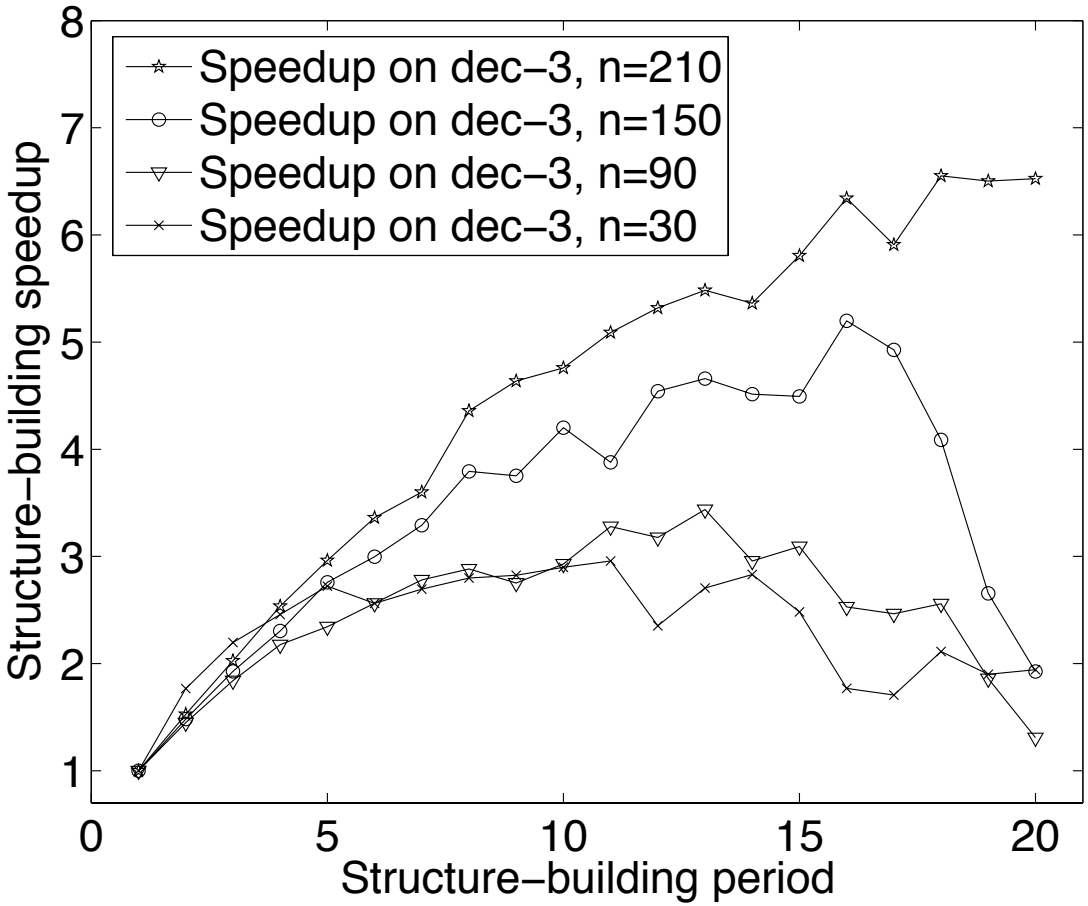
Experiments

- Vary problem size to study scalability.
- For each problem size use bisection to find sufficient population size to ensure 100% convergence in 10 independent runs.
- Repeat experiments for each problem size 10 times.

Observed statistics

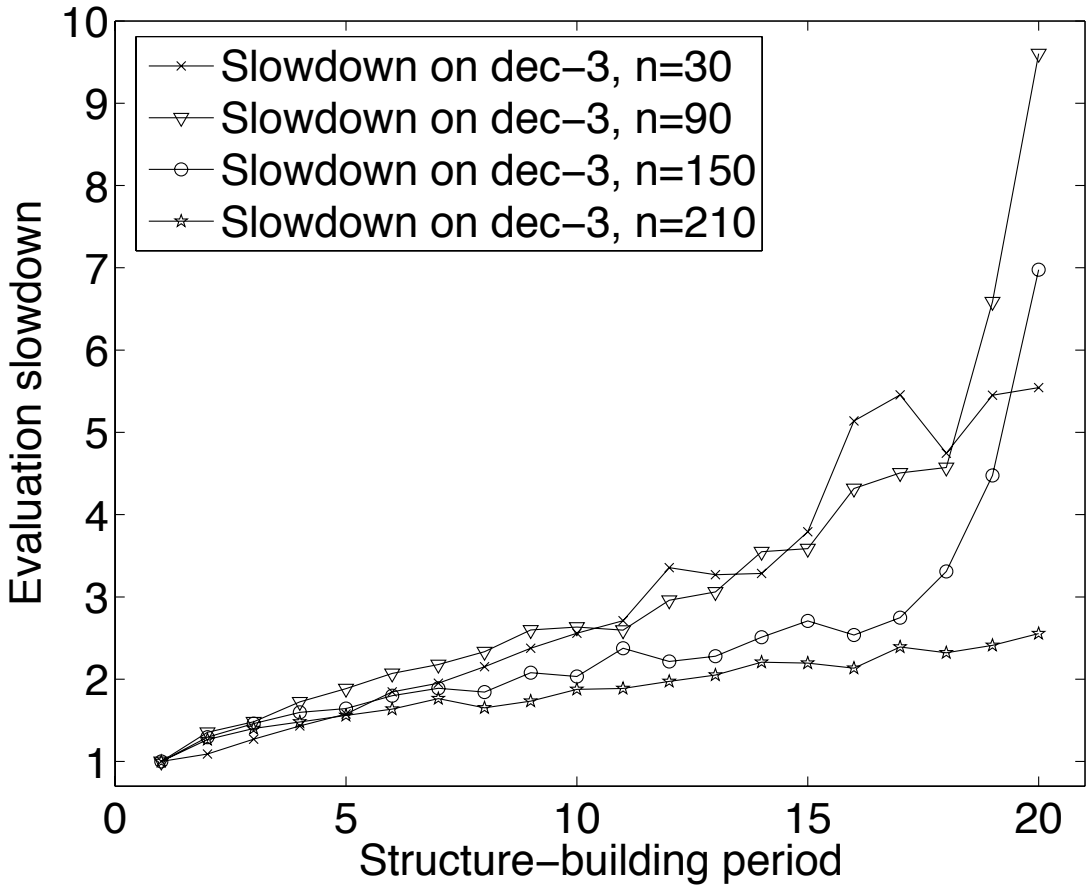
- Speedup of structure building vs. t_{sb} and problem size.
- Slowdown of evaluation vs. t_{sb} and problem size.
- Optimal speedup vs. problem size.
- Slowdown corresponding to optimal speedup vs. problem size.
- Overall CPU speedup vs. problem size.

Speedup of Structure Building vs. t_{sb} on dec-3



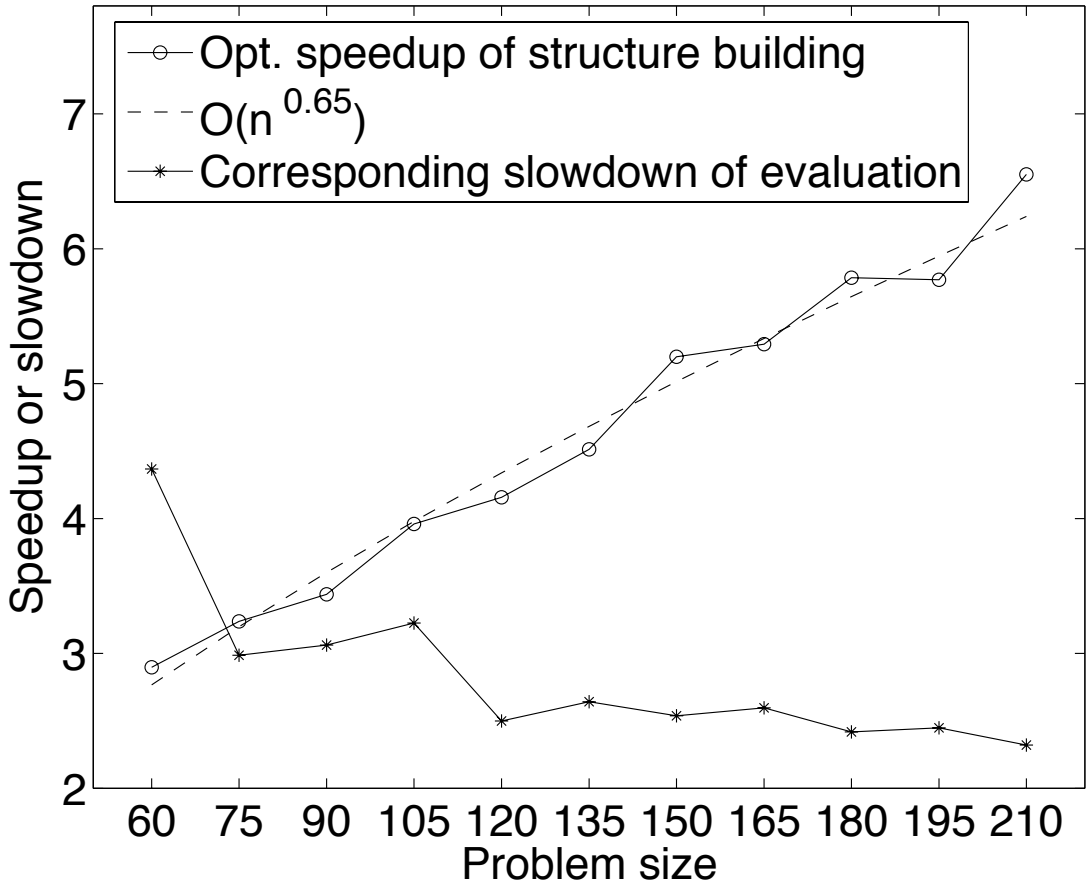
- Speedup first increases with t_{sb}, then drops down.
- Bigger problems yield bigger maximum speedups.

Slowdown of Evaluation vs. t_{sb} on dec-3



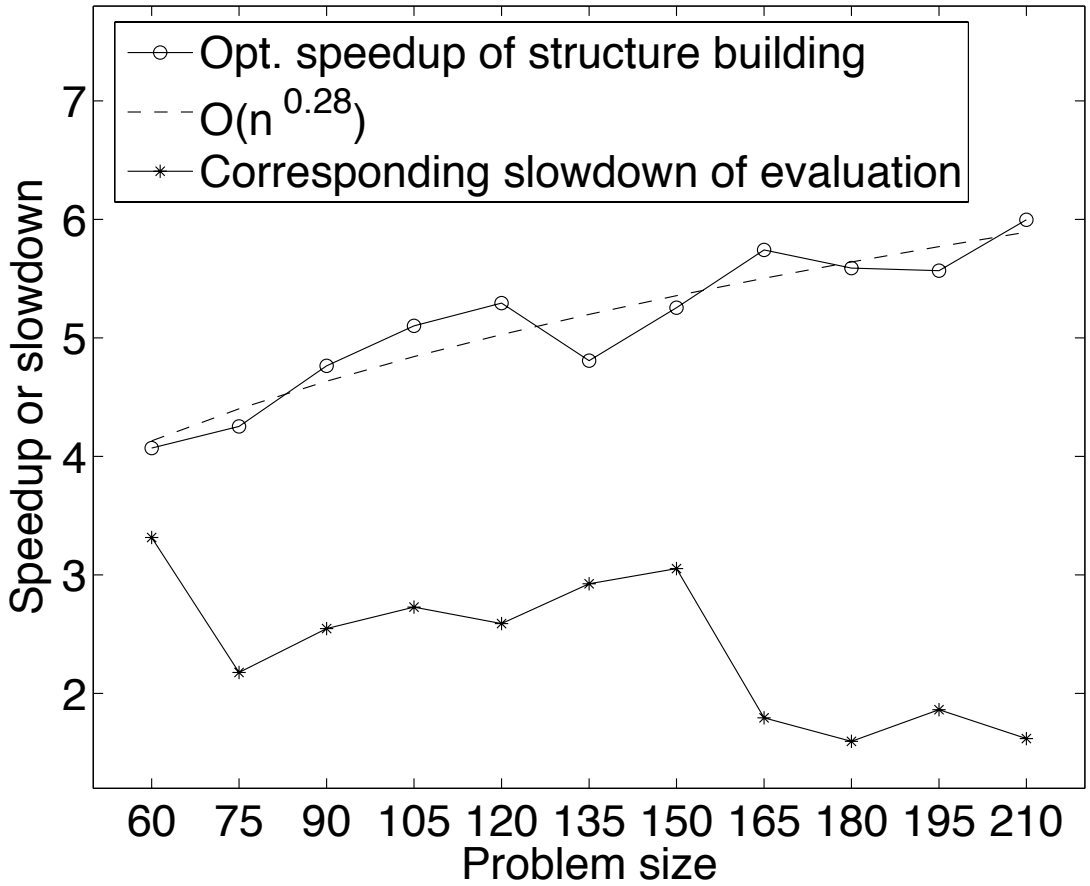
- Slowdown increases with t_{sb}.
- Bigger problems yield smaller evaluation slowdown!

Optimal Speedup and Corresponding Slowdown on dec-3



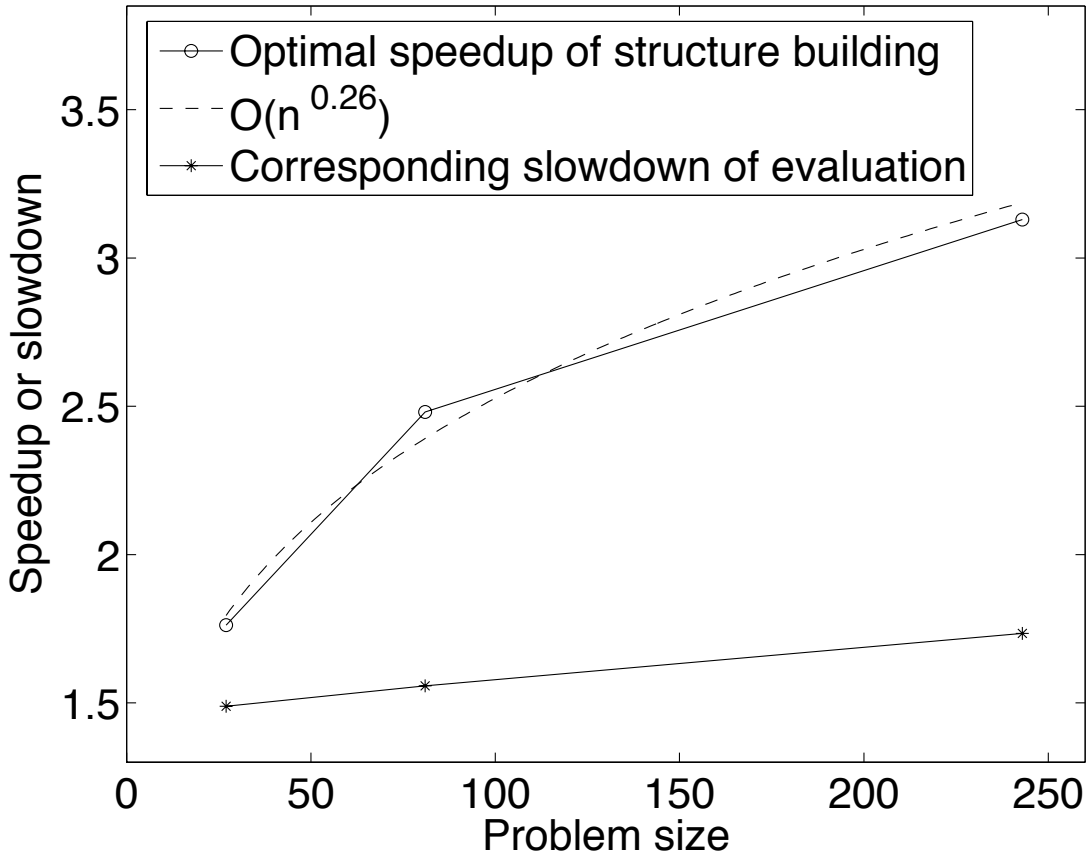
- Opt. structure-building speedup increases with problem size.
- Evaluation slowdown decreases with problem size!

Optimal Speedup and Corresponding Slowdown on trap-5



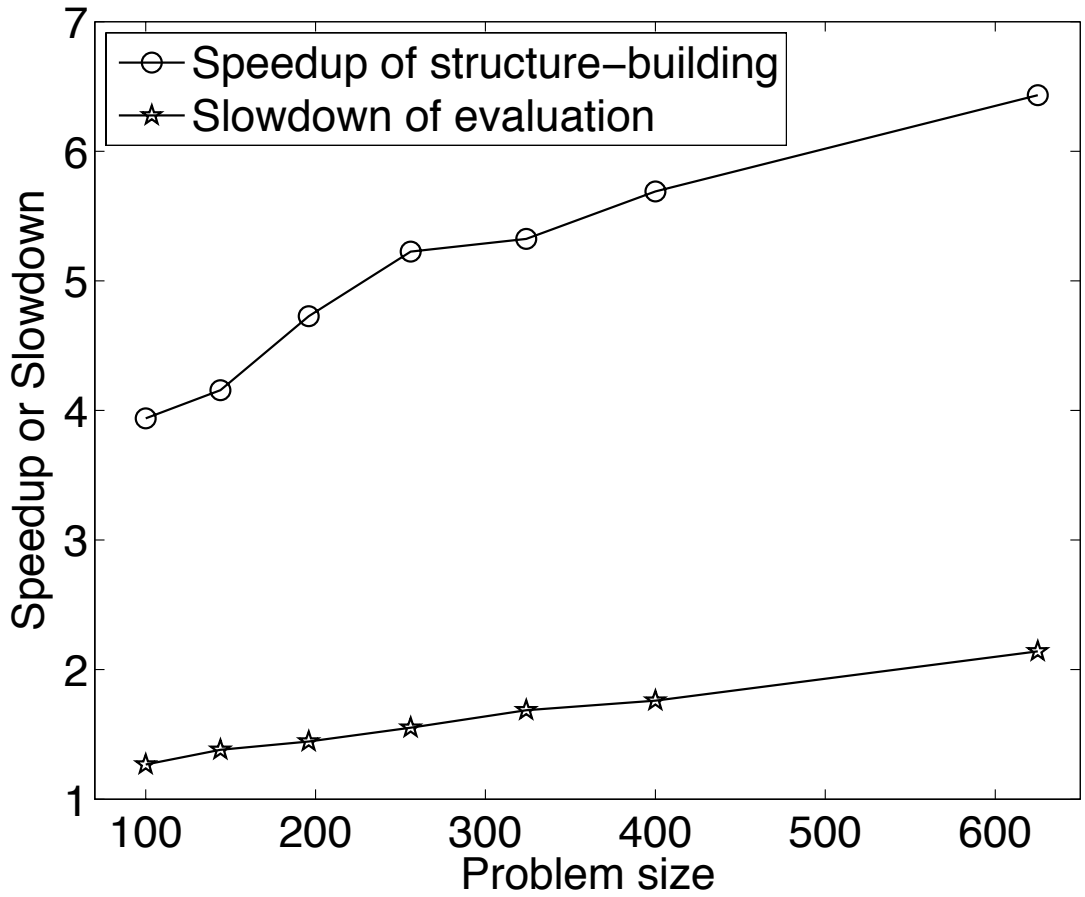
- Opt. structure-building speedup increases with problem size.
- Evaluation slowdown decreases with problem size!

Optimal Speedup and Corresponding Slowdown on htrap



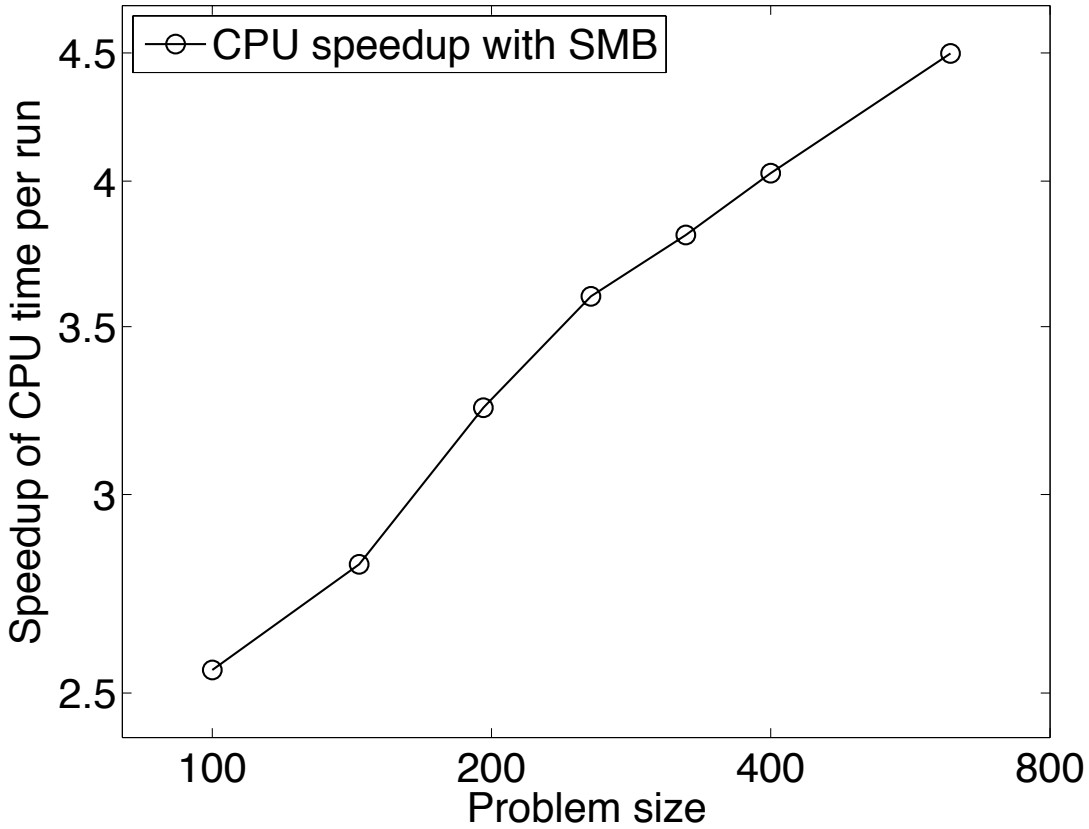
- Opt. structure-building speedup increases with problem size.
- Evaluation slowdown increases slightly with problem size...

Real-World Test: Struct. Building Speedup on Spin Glass



- Structure-building speedup increases with problem size.
- Evaluation slowdown increases slightly with problem size...

Real-World Test: Overall CPU Speedup on Spin Glass



- Overall CPU speedup increases with problem size!
- Without the need for determining optimal value of t_{sb}.

Summary and Conclusions

Sporadic model building (SMB)

- Build model structure only in some iterations.
- Remaining iterations use old structure.
- SMB speeds up model building in hBOA on a single processor.
- SMB can be used in other EDAs (e.g. ECGA).

Effects of SMB

- Speedup of model building.
- Slowdown of evaluation.

Summary and Conclusions (cont'd)

How well does it work?

- Significant speedup of model building (without parallelization).
- Speedup grows with problem size and decreases asymptotic complexity of model building.
- Slowdown of evaluation exists but is much less significant.
- If model building is the bottleneck, SMB yields great benefits.

Future work

- Adaptive schedule for SMB.
- Automatic setting of t_{sb}.
- Tradeoffs for specific problems (based on empirical evidence).
- More testing.